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An overview of solar photovoltaic energy in Mexico and Germany

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ABSTRACT

Energy is essential for our preservation and the improvement of our life-style. Today all major production of energy is generated from fossil fuels, which are non-renewable and significantly pollute the environment. Access to clean and reliable energy is crucial for assuring the development of countries such as Mexico. Mexico's economy is based on producing energy from fossil fuels[1] and the change to sustainable ways of life is still uncertain. It becomes essential to look at developed countries where the transition to sustainability has been rapidly increasing. This paper gives an overview of energy policies and the potential of solar photovoltaic energy in two countries: Germany, a world leader in the generation and development of photovoltaic technology; and Mexico, a country with great solar photovoltaic potential. It also describes the characteristics, advantages and disadvantages of photovoltaic technology, including BIPV systems.

Contents

1. Introduction

This paper aims to provide an overview of the current situation of Mexico's energy generation, the existing policies and programmes developed to encourage the use of renewable energy sources (RE) and particularly the potential use of photovoltaic technology. This will be compared to the use of RE systems in Germany with special focus on photovoltaic solar energy for electricity generation, which is one of the most rapidly changing and expanding technologies within the RE industry and whose potential greatly depends on the availability of

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[1] 91% of Mexico's energy is produced from non-renewable energy sources. Moreover, 36% of primarily renewable energy corresponds to the use of firewood for cooking used in a non-healthy and non-sustainable way [42]. GTZ is the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH (German Technical Cooperation, German Federal Ministry for Economic Cooperation and Development).

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solar radiation. This is clearly important in a country with an abundance of sunshine such as Mexico, with an average annual solar radiation of approximately 5 kWh/m^2/day [1].

The importance of producing energy from renewable sources such as photovoltaic depends on the following:

- An increasing demand for energy, especially in developed and some developing countries with fast economic growth, such as China and India.
- The need for energy in remote areas.
- A decreasing availability of fossil fuels.
- The reduction of CO_2 emissions and their effects on population health and air pollution.

2. The energy situation in Mexico and Germany

According to the Energy Ministry of Mexico (SENER), in 2011, 92% of Mexico's energy came from fossil fuels, mainly oil (65%) and natural gas (23%),[2] while just 7% was produced with renewable energy sources, where biomass represented 54%, geothermal 23%, hydroelectricity 20%, wind energy 0.9%, solar energy 0.9% and biogas 0.2% of the energy produced with renewables. In addition, nuclear energy[3] represented 1.15% of the total energy produced [2]. In 2012, Mexico had 1411 MW of installed capacity for energy generation based on renewable energy sources without including hydroelectric; this represented 2.6% of the total installed capacity for energy production in the country [3].

SENER has pointed out that reliance on fossil fuels for energy production in the country will not be enough to meet Mexico's future energy demand. From the year 2000 to 2011 Mexico's energy consumption increased 2.08% annually, while the energy production rate decreased 0.3% every year [4]. Hence, the government has predicted that in 2020 Mexico will suffer an energy deficit. Recently, Mexico's President Enrique Peña Nieto has presented a proposal to modify the Constitution in order to allow foreign companies to finance oil extraction from sources that demand advanced technology. In January 2013, total oil reserves in Mexico comprised 44,530 million barrels of crude oil equivalent (MMbpce); that figure is integrated by three different kinds of reserves: confirmed oil reserves (13,868 MMbpce), probable oil reserves (12,306 MMbpce) and possible oil reserves (18,356 MMbpce).[4] According to PEMEX (the government owned oil company) based on the energy production from 2012, Mexico's total oil reserves (also known as 3P) will last 32.9 years; however, if we consider only Confirmed oil reserves, the production will last merely 10.2 years [5]. In order to improve that situation, the SENER has established a number of objectives and actions that will take place during the next 14 years. There are three main strategies:

1. *Energy security*: To ensure Mexico's energy demand will be met with good quality and sufficient energy for its current and future population.
2. *Economic and production efficiency*: To use Mexico's energy resources as efficiently as possible, producing good quality energy at competitive prices and developing investment in infrastructure with maximum standards of health and safety practices.
3. *Environmental sustainability*: To reduce the environmental impact caused by the production and consumption of energy; making a sustainable use of hydro and soil resources.

On the other hand, in 2011, renewables in Germany accounted for 12.5% of total energy consumption and 20.3% of gross electricity consumption. The latter is expected to rise to 80% by 2050 [6]. In order to expand the use of renewable energy sources in Germany the government has implemented strategies such as the Renewable Energy Sources Act, which assure the acquisition of electricity from renewable sources to producers at a fixed price during 20 years [6].

According to the German Energy Agency [7], due to the increasing number of renewable energy systems installed nationally and increasing exports of technology, the renewable energy (RE) industry in Germany has considerably increased during the last 20 years, becoming an important economic factor. The photovoltaic sector in Germany employed 110,000 full time working people at the end of 2011 [7]; and it is expected to triple by 2030 [8]. This rising employment figure has led to a growing demand for skilled people and therefore, education programmes in this area have expanded within universities offering postgraduate courses, diplomas, or technical courses. The number of people from abroad going to Germany to study one of these specialisation courses is rising, producing a new source of income as well. On the other hand, the estimated PV-related labour in Mexico in 2010 was 146 jobs (including Research and Development, manufacturing of products, distribution of PV products, systems and installation companies and electricity utility businesses and government) [9].

In addition, Germany has become a world reference in the development and installation of RE. Expanding its use worldwide will secure a more sustainable future and a lower reliance on fossil fuels for electricity generation. Hence, in order to build up markets for RE and to expand its use in other countries, Germany has established an international cooperation where businesses, consultants and development cooperation institutions are sharing their experience with other countries. This is the case of Mexico. The *Deutsche Gesellschaft für Technische Zusammenarbeit* (GTZ) GmbH (German Technical Cooperation, German Federal Ministry for Economic Cooperation and Development) has been working closely with Mexico's government through the SENER, the Energy Regulatory Commission (CRE), the National Commission for Energy Efficiency (CONUEE), the Federal Electricity Commission (CFE), which is the public and only power utility and network operator in Mexico, and the Ministry of Environment and Natural Resources (SEMARNAT). The collaboration project, called "Sustainable Energy in Mexico", began in 2009 and will finish in 2013. The main aim of the project is to expand the use of RE in Mexico and to improve the energy efficiency of the country.[5] Another aim of the project is to assess the energy and economic potential of Mexico to use photovoltaic technology both in off-grid systems and as a part of the national electricity grid.

Moreover, this cooperative project also intends to encourage the use of one of the recent improvements in PV technology that is currently being widely used in Europe. This is the development of building integrated solar photovoltaic technology (BIPV), which

[2] Oil production and exportation in November 2011 represented 39.1% of the national public income of Mexico [43].

[3] There is only one nuclear plant in Mexico: Laguna Verde. It is located on the Mexico's Gulf coast in the State of Veracruz. This plant has been operating since 1990.

[4] *Total oil reserves* (3P) are the sum of confirmed oil reserves + probable oil reserves + possible oil reserves. *Confirmed oil reserves* are the term used to refer to energy sources commercially feasible, which are being currently harvested. *Probable oil reserves* include oil reserves that according to geological and engineering data could be commercially harvested, with at least 50% chance of recovering an amount of oil equal or greater than the sum of confirmed and probable oil reserves. Finally, *possible oil reserves* include those with less commercial harvest feasibility, where there is a 10% chance of reaching an equal or greater amount of oil obtained from the sum of confirmed reserves plus probable reserves plus possible reserves [44].

[5] More information regarding the "Sustainable Energy in Mexico" project is available at the GTZ web page: http://www.gtz.de/en/weltweit/lateinamerika-karibik/mexiko/27816.htm [accessed: 16.02.12].

allows architects to creatively integrate PV modules into roofs and facades of buildings contributing to the aesthetics of the construction without losing energy efficiency. The use of BIPV in private homes and businesses has been considered important because of its potential integration or even replacement of construction elements, and for the availability of large surfaces appropriate for installing BIPV.

According to the European Photovoltaic Industry Association (EPIA) in order to broaden energy supply based on clean technology such as PV, it is necessary to have both government and industry commitments. On behalf of industry, the investment in the expansion of production facilities is needed to improve PV technology (new manufacturing techniques and materials), increasing output efficiency and to lower production costs. On the other hand, the government commitment must focus on the development of regulatory frameworks such as feed in tariffs and the adaptation of building regulations to provide a greater incentive for the use of solar PV systems in the building environment. The case of the PV industry in Germany, including support mechanisms, will be analysed as an example of a worldwide reference expanding solar industry (EPIA, supporting solar photovoltaic electricity).

3. Building integrated photovoltaic systems

In order to fully understand the term building integrated photovoltaic (BIPV), it is necessary to include a brief description and characteristics of the photovoltaic solar technology.

3.1. Photovoltaic technology

Photovoltaic technology converts light into electricity directly without gas emissions or noise. This conversion is originated in the solar cells, which convert sunlight into electricity through the "photovoltaic effect", where *photo* means light and *volt* is the unit used to measure electric potential at a given point [10]. Most photovoltaic cells on the market are made with silicon and these can be *monocrystalline* (cells made from thin slices cut from a single crystal of silicon) or *polycrystalline* (cells made from a block of silicon crystals). Their efficiency[6] ranges between 12% and 17% [11]. These are arranged and connected in modules encapsulated behind a glass cover. Other types of PV cells are *thin film* cells made from very thin layers of photosensitive materials[7] placed on a low cost backing such as glass, stainless steel or plastic [11]. The use of thin film technology has increased during recent years because of their high flexibility, easy installation, efficiency under diffuse light of approximately 12% and a lifespan of 25 years [12].

A photovoltaic system is made by a group of solar modules that work together to produce electricity. The systems are arranged according to the particular application being configured and wired up as a complete structure with inverters, charge regulators and batteries. PV solar technology can be used as a standalone system or as a grid-connected installation. The first option is usually used in remote areas where there is no electricity grid; this allows powering a simple TV, or other household equipment or transport vehicle (Fig. 1) or to even power an entire house or building (Fig. 2). In this case the energy yield of the PV modules must match the energy requirements by means of storing energy or using a hybrid system.[8] The second option is the grid-connected installation; here the electricity generated goes directly to the public electricity grid.

Fig. 1. Motorbike powered with PV (2010).

Fig. 2. House with PV in a residential area in Erlangen, Germany (2010).

The main advantages of photovoltaic energy generation are the following:

- Zero CO_2 emissions and no noise while producing electricity.
- Systems have a long lifespan of approximately 30 years.
- Wide range of applications, from a small fan or calculator to powering a house, office building or even large generation plants.
- The use and disposal of silicon do not represent any environmental hazard, plus it is an abundant material.
- Only the sun is needed to produce energy, this fuel is free and constant,
- PV modules can be recycled avoiding energy consumption used for their production and also contributes reducing their price,
- PV modules require low maintenance,
- Research is carried out permanently to improve the efficiency and appearance of cells and systems, while trying to reduce their cost. In addition, research is being conducted for recycling old PV modules and cells in order to save money mainly by

[6] The performance of a solar cell is measured through its efficiency to convert solar energy into electricity. A typical commercial PV cell has an efficiency of 15% [45].

[7] Thin-film solar cells can be made with one of the following materials: amorphous silicon, cadmium telluride or copper indium diselenide [46].

[8] Hybrid systems based on photovoltaics are complemented by other renewable energy technologies such as wind power, hydropower and combustion engines.

using natural resources and reducing the amount of energy needed to produce new cells.

The main disadvantages of photovoltaic energy generation are the following:

- A *Natural Limit* imposed by technical, ecological and land-use limits [13]. This natural limit includes:
  - Great reliance on technology development. PV industry and the generation of electricity with PV systems depend on the development of solar technology, specially the improvement of the cells' efficiency to transform solar energy into electricity. In addition, the cost of PV installations must continue to drop in order to become a widely used energy resource.
  - Ecological and land-use limits refer to geographical conditions that make possible to harvest solar energy. According to Elliott [14] despite the large amount of solar energy falling on the Earth (around 90,000 TW equivalent), only around 1000 TW is available for human use. This figure is limited by technical factors such as conversion efficiency, land access limits and the diffuse and intermittent nature of this natural resource. Moreover, the amount of land needed to build and operate a big scale PV solar plant can also be a limitation.
- *Energy limits*. Experts and government authorities have argued that large amounts of energy are needed to produce PV technology, some people even say that PVs generate less energy during their lifetime than the required during the manufacturing of the photovoltaic cells and modules. Elliott [14] has stated that the embedded energy costs associated with renewables are mostly low and less than for other energy technologies. Even though PV is the most energy intensive renewable energy technology, still generates nine times more energy over its lifetime than is needed for cell fabrication [15].
- Finally, expensive high technology, large amounts of rare materials, and highly skilled and expensive construction personnel are needed to build and operate a PV system.

3.2. Building integrated photovoltaics (BIPV)

Building integrated photovoltaics are modules that can be aesthetically integrated into roofs and facades to produce energy. In general, PV modules installed on top of a roof or building material are considered to be BIPV (Figs. 3 and 4). Currently, some countries such as France consider BIPV as the only modules that can replace a building material either on a roof or façade; for

Fig. 3. BIPVs in a house in Erlangen, Germany (2010).

Fig. 4. BIPVs in a prototype house of the Decathlon Solar Design Competition 2010, Madrid, Spain (2010).

instance, they can replace a window or a canopy structure covering an atrium or a courtyard. These are called "fully-integrated systems", and nowadays are very popular among designers because the government has applied the highest feed-in tariff to this type of system, which means people will get more money for the electricity produced by a "fully integrated" PV system than by a regular BIPV system (from 1 January 2011) [16].

Current research focuses on developing cheaper, more efficient, more flexible, lightweight, translucent and coloured BIPV modules. Also, new materials for PV cells are also being tested, such as organic PV (OPV).

4. Solar energy potential in Mexico

Mexico has an average solar radiation of 5 kWh/m^2/day, and in some parts of the country it reaches 6 kWh/m^2/day [17]. This is high compared to other countries; for instance, the average solar radiation of Germany is 3.2 kWh/m^2/day [18]. A few countries in Latin America, including Mexico, have developed solar irradiance maps to show the country´s solar energy potential in order to encourage industry development (Fig. 5). In addition, Mexico is the second largest economy in Latin America and has a large territorial extension. All these characteristics underline the country's excellent conditions to harness energy from the sun. Nonetheless, this potential has represented very little benefit so far for the energy generation in Mexico, mainly due to poverty, lack of awareness, lack of government support to mitigate climate change, reduce the reliance on fossil fuels, or investment in innovation and advertising strategies [19].

According to the National Survey Report of PV power application in Mexico [20], the budget for PV projects research during 2010 was around 20 million Mexican pesos (1.15 million euros, see footnote10); however, no funds were allocated for PV production, installations or feed-in tariffs. Fortunately, though slowly, this situation is changing. During 2012 two large scale grid-connected PV plants were installed in Baja California. They are operated by CFE, one is a 1 MW capacity plant that started commercial operation during the first semester of 2012; and the other one is a 5 MW capacity plant currently undergoing a pre-operational testing stage.

In addition, according to CFE in 2012 around 1000 grid interconnection contracts were signed by private parties for the installation of 7.7 MW of PV capacity. A total of 14.5 MW PV panels capacity were installed in Mexico during 2012 [21].

The importance of incorporating other energy sources different from fossil fuels for electricity generation relies on the fact that the

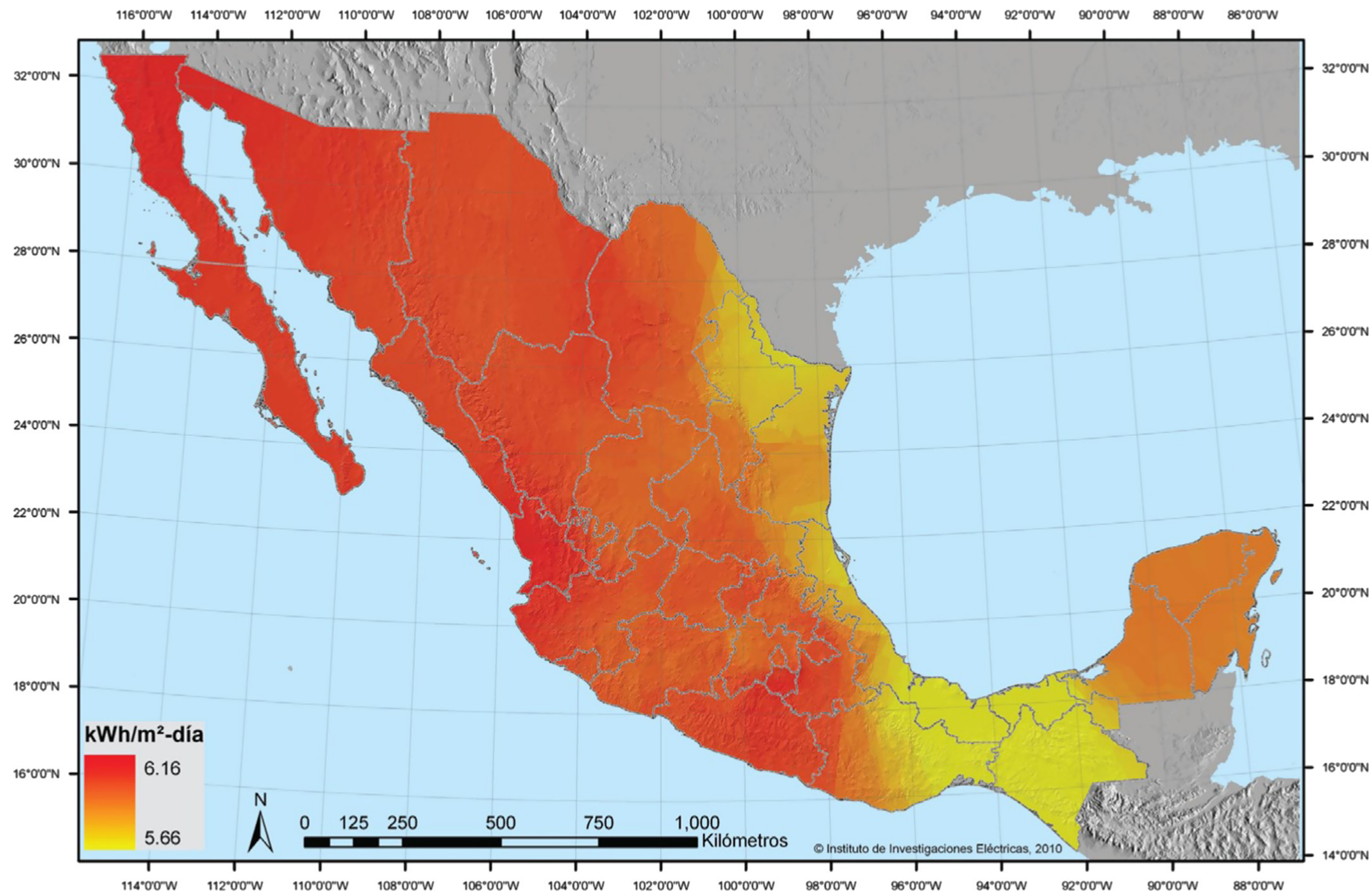

Fig. 5. Mexico's average solar radiation distribution (Instituto de Investigaciones Eléctricas & SENER. Available from: http://sener.gob.mx/webSener/res/1803/Solar.pdf [accessed 18.09.13]).

Table 1
Annual solar yield for different building elements for Mexico city.

Mexico city	Flat roof	Sloped roof	Façade
Latitude: 19.2°N Longitude: 99.1°W Altitude: 2277 m Best solar yield: 1903 kWh/m^2	Solar yield: 95%	Best tilt: 18° Good yield area on south axis: 0–60° Good yield area for 30° tilt: −120° to +120°	Best azimuth: +−60° Best yield: 55% Good yield area: −115° to +115°

Mexican population will continue to increase, reaching 121.7 million in 2030 and 126.9 million inhabitants in 2050 [22].[9] Therefore, the CFE and the SENER have predicted a consumption of electricity of around 228.8 TWh for 2012 and 404.7 TWh for the year 2025. These figures represent 4.3% annual increase [23].

Within the renewable energy sources used in Mexico to generate energy, hydraulic represents 88% and geothermal 8%, while photovoltaic only 0.15% [24]. Nowadays, Mexico has installed only 52 MW of photovoltaic systems capacity [21] contributing 0.09% to the country´s annual gross electricity generation [2], while Germany has installed 32,000 MW PV capacity contributing 4.6% to the annual gross electricity generation [25], even though Germany is a country with lower solar radiation and less population [18].

The International Energy Agency (IEA) published a document in 2002 containing methodology, case studies and rules of thumb to determine the BIPV potential of different countries for roofs and façades. According to their study, Mexico city has the following annual solar yield (irradiation on the surface) for different building elements (Table 1).

In comparison, Table 2 shows the annual yield for Zurich, Switzerland, the geographical data of that city is similar to the city of Nuremberg in Germany (latitude: 49°N and longitude: 11°E). Comparing both cities´ data, Mexico city has a higher solar yield per m^2, a greater solar yield with flat and sloped roofs, but a lower solar yield on façades.

5. Electricity costs in Mexico and Germany

Current domestic electricity costs in Mexico are divided into eight different levels according to the consumption, with the lowest consumption being 250 kWh/month; and the highest 2500 kWh/month. In addition, the country is divided into six different geographical regions with different tariffs, this division is based on the average minimum temperature registered during the summer season, which varies between 25 and 32 °C [2]. The production of electricity supplied from the public grid costs around

[9] The Mexican population registered in the last census in 2010 was 112 million inhabitants [47].

Table 2
Annual solar yield for different building elements for Zurich.

Zurich	Flat roof	Sloped roof	Façade
Latitude: 47.4°N Longitude: 8.6°E Altitude: 556 m Best solar yield: 1167 kWh/m^2	Solar yield: 91%	Best tilt: 30° Good yield area on south axis: 0–75° Good yield area for 30° tilt: −110° to +110°	Best azimuth: 0° Best yield: 65% Good yield area: −100° to +100°

4.12 MX$/kWh (inc. taxes), which is equivalent to 0.237 euros/kWh[10] [26]. However, Mexico´s government subsidises around 65% of the electricity cost (except for users with the highest consumption rate and tariff), therefore, the end user pays around 1.50 MX$/kWh, which is equivalent to 0.09 euros/kWh.

On the other hand, household electricity prices in Germany are [27]: 0.28 euros/kWh (with a consumption of 3500 kWh/year) and 0.26 euros/kWh (with a consumption of 7500 kWh/year). These prices include all taxes. Although German prices are some of the highest in Europe, only slightly lower than Denmark, they are not very different from Mexican prices, which are more expensive than electricity costs in Spain, the United Kingdom or France.

Apparently two of the main problems for the expansion of the PV market in Mexico are the small electricity fees paid by the end user, and the high price of PV technology because it is mainly imported from countries like Germany and China.[11]

Until recently there were three international PV module makers with production facilities in Mexico: Kyocera, Unisolar and Sanyo. Unfortunately, the latter closed its operations in Mexico in 2012 [21]. The products of the two other companies are for the export market only. Moreover, there are two Mexican companies, ERDM and Solartec, whose PV modules are sold in the domestic market and part of the production is exported to Central America and the Caribbean [28,29].

6. Mexico´s market niches for PV systems

One of the main steps taken to develop the use of renewable energy resources (especially solar energy), in order to generate electricity, has been the assessment of Mexico's potential and market niches. In 2009 the SENER, the CONUEE and the GTZ published a document with the results of a study whose main purpose was to show possible existing market niches[12] for photovoltaic systems (PV) in Mexico in the residential sector and the industrial and commercial sectors, focusing on grid-connected systems only [30]. This document clearly illustrates the PV potential of the country, with simulations made under three different scenarios for 29 cities in Mexico, considering the prices of PV systems per kW$_p$ installed:

1. "Current prices": From autumn 2007 in Mexico.
2. "Conservative outlook": Assuming a 20% price reduction within 5 years.
3. "Optimistic outlook": Assuming a 50% price reduction within 5 years.

Results show that today scenario 1 is not economically feasible; it would be more expensive to produce energy from PVs than from the grid with no PVs. There are no market niches for grid-connected PV systems except for households within the highest level of electricity consumption, with the most expensive electricity tariff and located in areas with at least the average solar radiation of Mexico. Then, if part of the electricity supplied comes from a PV system, the tariff could drop and the user could have some benefits. Currently, according to the SENER, the only people who can have some economic benefits installing Solar systems are people using solar thermal water heating systems and PV systems for rural electrification in isolated communities [31].

However, scenario 2 shows that consumers with the highest tariff and below (for most of the locations) could be benefited in 5 years, having an electricity cost per kWh with a grid-connected PV system lower than with a grid electricity with no PVs.

Scenario 3 shows that by decreasing the prices of PV systems in Mexico by 50%, most consumers (excluding those with the lowest electricity tariff) will benefit from having a grid-connected PV system. This cost-saving scenario could attract a great number of investors creating an important PV market and industry in Mexico. Around 1.5 million homes in Mexico could install PV systems with a clear economic benefit considering polycrystalline systems with 16% efficiency [32].

6.1. Regulations and financing in Mexico

In 2001 the government of Mexico approved a special regulation to define the terms: renewable energy sources, connection to the national grid, excess of generated energy or lack of renewable energy, etc. It is important to mention that this document acknowledged the intermittent availability of renewable energy sources and possible ways to manage this feature.[13]

In 2007, the regulatory body for the Mexican electric and gas sector, the Regulatory Energy Commission (CRE), approved a Contract for Interconnection of Small Scale Solar Energy Sources (Contrato de Interconexión para Fuente de Energía Solar en Pequeña Escala), which is based on the rated power capacity (kW$_p$) and not on the annual electricity production (kWh). This contract allows investors or any person to produce electricity connected to the national electric grid for up to 30 kW$_p$ of power capacity. This contract applies for photovoltaic energy systems of up to 10 kW$_p$ for residential uses and up to 30 kW$_p$ for other low voltage uses [33]. This type of contract, based on the rated power capacity, does not sufficiently motivate investors to spend on highly efficient PV systems.

In November 2008 the National Law for the Use of Energy from Renewable Sources and Financing the Energy Transition was

[10] Currency exchange rate on 10 September 2013: 1 Euro= 17.3667 Mexican pesos [48].

[11] There is no Mexican production of grid-connected PV inverters. There are several battery manufacturers and three manufacturers of charge controllers. The needs on DC switchgear for PV applications are covered with imported products. Supporting structures for PV application is not a real market in Mexico; however, there are industrial facilities for manufacturing metal structures for other purposes [49].

[12] *Market Niches* mean opportunities for a financially feasible use of grid-connected PV systems in Mexico [50]. The study considered polycrystalline PV modules with an efficiency of 16% and 20 year lifespan.

[13] Document published in the DOF (official publication) on 7 September 2001 [51].

published (Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética); together with the Law for Sustainable Use of Energy (Ley para el Aprovechamiento Sustentable de la Energía). Both laws state the importance of seriously considering the generation of energy from renewable sources in order to reduce Mexico′s dependence on fossil fuels (coal, oil, and gas) but also to introduce "clean" technology diminishing the generation of CO_2. Within this framework, a special fund was created to finance programmes and the introduction of new technology for the energy transition and extended use of renewable energy sources to produce electricity. It was stated that this Fund[14] will receive 3 billion Mexican pesos each year, approximately 173 million euros[15] (so far the money was approved until the year 2011) [34]. The government has also published other documents in order to regulate the production, use and transmission of energy generated by renewable sources. These are the following:

- Regulation for the use of renewable energy and financing the energy transition (*Reglamento de la Ley para el Aprovechamiento de las Energías Renovables y el Financiamiento de la Transición Energética*) (published on 2 September 2009).
- Regulation for the sustainable use of energy (*Reglamento de la Ley para el Aprovechamiento Sustentable de la Energía*) (published on 11 September 2009).
- Special programme for the use of renewable energy (*Programa Especial para el Aprovechamiento de Energías Renovables*) (published on 6 August 2009).
- Policy and regulation for the financing procedures promoted by international organisations (SENER, *Políticas y medidas para facilitar el flujo de recursos derivados de los mecanismos internacionales de financiamiento*).

In general, financing from the Mexican Fund for Energy Transition is focused on developing rural electrification with PVs in isolated areas of Mexico. The objective is to light 50,000 homes in 5 years (2007–2012) in 2500 communities in poor areas of Oaxaca, Chiapas, Guerrero and Veracruz (South and South–East regions of Mexico). In addition, there is a financing programme for municipal public lighting powered with PV [35], and there are other funds for research projects and technology development related to clean energy, energy efficiency, new products and materials, and energy source diversification [36].

Other financing possibilities for projects related to reducing climatic change and CO_2 in Mexico are provided by international funds such as World Bank, Global Environment Facility, Inter-American Development Bank and the European Investment Bank.

In summary, the funds available in Mexico to finance renewable energy projects are destined to large public or private projects. The only programme that is focused on end-users of electricity is a programme called sustainable lighting and consists of replacing household incandescent light bulbs for more efficient lamps to reduce electricity consumption [37]. Therefore, there are no financial instruments that give economic incentives or benefits to regular citizens for investing in energy production with renewable sources. That of course is holding back the development of the PV industry in Mexico.

Research and development (R&D) in Mexico is led by the National Science and Technology Council (CONACYT). That organisation together with the SENER issued a call for proposals for the creation of a Mexican Innovation Solar Energy Centre. Proposals are in the evaluation phase. In addition, the CFE is analysing and testing the impacts of large scale PV systems on distribution lines and the advantages of PV mounted roof tops, especially in the north western region of Mexico. This region has an elevated solar radiation throughout most of the year and a high demand for air conditioning in the summer season [21].

6.2. Regulations and financing in Germany

On the other hand, Germany is rated third among countries in the world in terms of installed PV capacity, after Japan and the US [38]. At the end of 2012 more than 32.4 GW of PV capacity was installed in Germany, contributing 4.6% to their annual gross electricity generation [25]. They have three widely known financing instruments to encourage people to invest in PV systems. These supportive measures include capital cost buy-downs, performance incentives, and low-interest loans. At the national level the programmes are the following [39]:

- 1000 *Solar Roofs Programme*: Launched in 1989, provided rebates for up to 60% of system costs.
- 100,000 *Solar Roofs Programme*: Implemented in 1999, with an initial goal of installing 300 MW by 2004. This programme was funded with 560 million euros; it provides 10-year low-interest loans with no money down and no interest payments for two years. This represents a subsidy of around 20%.
- *Renewable Energy Sources Act* (*EEG*): Applied in April 2000. It determines the procedure of grid access for renewable energies and guarantees favourable feed-in tariffs (FiT) for electricity production, around 0.17 euros/kWh in January 2013 [25]. Starting in 2001 with a feed-in tariff of 0.506 euros/kWh, the tariff will decline by 5% each year, and according to the last amendment of the EEG approved in April 2012, the FiT scheme is now limited to 52 GW of total installed PV capacity. This funding instrument has proven to be very effective if the feed-in tariff per kWh is higher than regular electricity costs.[16]

Moreover, some municipalities in Germany also offer production incentives funded by surcharges on utility bills [40]. These could be combined with the national programmes. This type of incentive is destined for small PV installations, which are not considered in the financing programmes for RE and PV production in Mexico.

Despite the current economic crisis, German banks are still loaning money for the construction of small and large scale installations of PV systems. For instance, the German Development Bank has subsidised loans for renewable energy projects of up to 10 million euros; with an average interest rate of 5% [41]. In addition, there is an easy access to loans for small PV systems. Financing is based on the applicant´s credit rating and his regular monthly income. The interest rate is irrespective of the loan duration and it is around 5.6%.

Finally, there is another type of financing through property loans. Anyone who owns a house in Germany can obtain a loan for 15 years at a fixed interest rate of 4.5%. The main disadvantage is that the system has to be rather large because banks prefer to loan at least 25,000 euros, which corresponds to a 7 kW power system [41].

There is a large list of companies involved in PV in Germany: 23 inverter manufacturers, 67 companies with PV productions (wafer, cells and modules), 46 PV equipment manufacturers and there are

[14] Fondo para la transición energética y el aprovechamiento sustentable de la energía [52].

[15] Currency exchange rate on 10 September 2013: 1 Euro = 17.3667 Mexican pesos [48].

[16] The levelized costs of energy (LCOE) for a small rooftop PV system in Germany are around 0.15–0.18 euros/kWh, while the electricity price for private homes is around 0.25 euros/kWh. Therefore, the investment on PV installations is attractive even without the FiT scheme [25].

Table 3
Comparison of economic incentives to RE and PV installations.

Type of incentive	Mexico	Germany
Special funds and programmes	Special Fund for Energy Transition and use of RE: 173 million euros/year	1000 Solar Roofs Programme: sponsors up to 60% of system costs (launched in 1989)
	Power Integral Services: rural electrification with off-grid PV systems for 50,000 homes	100,000 Solar Roofs Programme: 560 million euros, provides 10 year low-interest loans
	Programme for financing municipal public lighting	Renewable Energy Sources Act (2000): FiT for electricity production (0.17 euros/kWh in January 2013). This scheme is limited to 52 GW of total installed PV capacity
	Sustainable lighting programme: replacing household incandescent light bulbs for efficient lamps	Municipal level: offer surcharges on utility bills for small PV installations
	Support of research projects by the energy and sustainable energy fund: SENER+CONACYT. This fund is equivalent to 0.13% of the value of oil and natural gas extracted by PEMEX	German Development Bank: loans for RE projects of up to 10 million euros with an average interest rate of 5%
	Funding of low carbon technology projects by International organisations: World Bank, IDB, Global Environment Facility, European Investment Bank	Other banks: easy access loans for small PV installations with an interest rate of 5.6%
	Funding by Nacional Financiera (NAFIN): up to 25% of the cost for installation or operation of RE projects	Property loans for PV systems: anyone who owns a house can obtain a loan for 15 years at a fixed interest rate of 4.5%
Tax exemptions	Currently, there is a tax exemption on RE (including PV) equipment that has been operating at least for 5 years	
	Full tax exemption on import and export of equipment and materials used for research and technology development by research centres and universities	

additional manufacturers of materials for PV modules and system components. In 2012, around 110,000 workers were employed in the PV industry in Germany [25].

Regarding research and development (R&D) related to PV, it is currently conducted under the "Research for an environmental friendly, reliable and economical feasible energy supply", which came into force in 2011. This programme is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), and the Federal Ministry of Education and Research (BMBF). In 2012 the BMU supported 238 R&D PV projects which amounted to 51.7 million euros. In addition, in 2010 BMU and BMBF started the Innovation Alliance PV projects, allocating 100 million euros to support this initiative. At the moment, there are 19 R&D projects in progress, whose main aim is to significantly reduce PV production costs in order to enhance the competitiveness of Germany´s industry [25].

Table 3 compares economic incentives to PV solar energy available in Mexico and Germany.

7. Discussion and conclusions

As in many other countries, Mexico must implement strategies to diversify the sources of energy generation, assuring the generation of enough energy for its population but also guaranteeing the preservation of the natural environment by generating clean energy. A diversification of the technology to generate energy will contribute to the competitiveness, economic growth and sustainable development of Mexico, all those achieved by eliminating the risk of depending only on fossil fuels to keep the country running. Gischler and Janson [53] have pointed out that promoting distributed generation (DG)[17] of energy done with renewables in Latin America would reduce the cost of electricity for a country as a whole, with advantages such as reducing global environmental externalities (green-house gas emissions), reducing local environmental and social externalities (for instance, production of electricity from fossil fuels generates negative impacts on the environment and human health, mainly due to air pollution, but also imposes damaging environmental impacts and risks during extraction processes), supporting development of a new "green" technology and industry, increasing energy security, reducing system losses, increasing access to energy and creating green jobs.

Some authors have pointed out the present Latin America´s challenge of redefining the energy model for the region. This results from foreseeing a 3% annual economic growth combined with improvements in quality of life and population growth in Latin America; hence the region must double its installed power capacity to about 600 GW by 2030 [54]. Fortunately, the region could produce over 78 PWh from solar, wind, marine, geothermal and biomass energy (also known as Non-Traditional Renewable Energy Technologies NRETs); and the corresponding nominal peak capacity would be around 33 TW (17,000 GW for PV), which covers any foreseeable regional demand even considering technical limitations [54]. According to the same authors, the projected energy demand growth in Latin America for 2050 would be around 3.5 PWh, which would only amount to 4% of total available technical potential.

Even though Latin America´s share of global investment in NRETs and hydropower is modest (5.4% of the total), the tendency is to increase the amount of major projects responding to regional energy potential and to growing demand of electricity [54]. Continuous dropping costs of renewables is helping to the expansion of these technologies in Latin America; especially PV is closer now to the fully commercial phase, where it can compete with hydropower and fossil fuels costs. Module PV prices have dropped from 1.33 euros/W in 2009 to 0.59 euros/W in 2013.[18] It has been predicted that over 2 GW of PV capacity could be installed in Latin America by 2016 [54].

Vergara et al. [54] have identified site specific technical potential for renewables in Latin America and the Caribbean; where Mexico is marked with solar, wind on-shore and biomass potential.

[17] Gischler and Janson [53] define distributed generation (DG) as "electricity generation that is connected to the distribution network". DG then, is a grid-connected system, located at customer premises or close to the load being served, and implemented on a smaller scale.

[18] Currency conversion from US dollars to euros was made considering 1 dollar=0.738 euros. Source: http://www.xe.com/currencyconverter/convert/?Amount=0.8&From=USD&To=EUR [accessed: 16.10.13].

In addition to diversifying Mexico′s energy sources, it is also important to reduce the consumption of energy, especially in the construction and operation of buildings, in the industry and retail sectors, as well as in our everyday life.

Mexico′s sustainable development relies on producing clean and reliable energy, an equal distribution of energy and a sustainable access to it for every person living in Mexico. In order to achieve this, it is essential to support research projects to produce energy technology, and to design and implement energy policies that allow people access to credits for renewable energy installations and electricity production on domestic and commercial scales. In the case of PV, this must be accompanied by a feed-in tariff system at a predetermined price during a predetermined period of time to encourage people to invest in this technology.

There are some social benefits and avoided costs of grid-connected PV power generation that have been pointed out by Vergara et al. [54]. These benefits were quantified into a dollar figure using established methodologies referenced by the authors and were obtained from several studies mainly developed in the United States (Table 4). Figures show that in Latin America PV and most NRETs are societally cheaper than even the most inexpensive fossil fuel technologies [54].

Even though Mexico′s photovoltaic industry is behind some developed countries, such as Germany, future market and energy trends are showing an increasing and almost compulsory switch to using solar technologies for energy generation. Sooner or later Mexico will have to support the development of PV and therefore it is important to learn from the evolution of this technology in other countries, so mistakes can be avoided and a strong PV market can be provided.

It is important to consider that small PV installations connected to the grid usually lose around 30% of electricity during transportation, and this could be avoided if the electricity is used near to the PV installation that is generating energy.

Here, some recommendations for creating a well-positioned PV and BIPV market in Mexico are presented. These can be divided into three main topics: awareness, financing and regulatory framework, and training.

1. *Awareness*
   - Creating awareness about the benefits (social, environmental, economic) of switching to and investing in solar technologies, among the public, politicians, investors and designers.
   - Distribute knowledge among designers and investors regarding the advantages of PV systems and BIPV. This can be achieved through information and networks provided by the solar industry, private or public organisations working on sustainability aspects, professional organisations,[19] universities and other education institutions. Several conferences, courses, exhibitions and design contests related to sustainability and clean energy are taking place in Mexico.
   - In addition, public forums in all major cities around the country must be organised to let the general public know about the advantages, costs and economic incentives related to PV solar energy. Other activities to distribute knowledge could include exhibitions in museums and public areas such as parks, pedestrian streets, bus and metro stations; TV and radio shows, and visits to exemplary buildings with LEED certification and PV installations.
   - Create Internet forums specialised on PV technology, and an official database and web site with state of the art information regarding PV technology, publications and events, PV companies located in Mexico, and a list of certified people and companies that are able to design, install and maintain PV systems in Mexico. This could be similar to the information offered by DENA (German Energy Agency) and EPIA (European Photovoltaic Industry Association).
2. *Financing and regulatory framework*
   - Finance research and development of cost-competitive and efficient PV and BIPV technology in order to produce it in Mexico, reducing the technological reliance on developed countries.
   - Implement government policies and programmes that could offer clear benefits to consumers. For instance, tax credits for new installations, feed-in tariffs mechanisms, sales tax exemptions and low-interest loans have already being successfully implemented in other countries.
   - Learn from other countries´ initiatives and results, such as Germany.
   - Favour the German model of small installations in the houses where electricity could be used straight away eliminating the loss of energy in transportation and where excess of electricity is sent to the public grid. In Mexico, this approach could be economically beneficial to end-users if PV installations help to reduce the amount of electricity consumed in the building in order to keep the system within the subsidised tariff of CFE.
   - Avoid large scale PV installations with strong government subventions to the electricity tariff produced by RE. In the end, this model could originate a huge electricity bill paid by customers and the government itself. In other countries, like Spain, this system has provided huge benefits to some companies but has been abandoned for the costs that it has produced to users and the government. It has also created large corruption models where municipal administrations have approved installation permits at huge prices.
   - Focus the implementation of photovoltaic systems in urban areas where energy consumption is highest due to the concentration of people and their current life style, including the use of motor transportation, dispersed city growth, fragmentation of urban areas within small units, industry and retail buildings expansion, new housing developments and the use of technology such as computers, telephones, household appliances, etc.
   - Improve and support the development of programmes such as the CFE´s Grid Interconnected Photovoltaic

Table 4
Avoided costs and societal benefits of PV electricity generation.
Source: Reproduced from Vergara et al. [54].

Value	Range (euros/MWh)
Value of avoided GHG emissions	2.4–14
Value of avoided criteria pollutant emissions	0.07–13.7
Avoided generation capacity cost (relevant if peak demand occurs in daytime)	21.3–168.7
Avoided cost of additional transmission infrastructure	0.29–73
Avoided distribution cost	1.39–21.5
Avoided cost of fuel (natural gas)	23.7–71
Avoided generation and transmission and distribution losses (system losses)	1.09–31.4
Value of grid support (ancillary services)	0.36–2.04
Value of fossil fuel price hedge (risk premium)	2.99–6.95
Total	**56.7–375.4**

Note: Costs were converted from US dollars to euros[18] (see footnote 18).

[19] Some Mexican organisations related to sustainability and solar energy include SUME (Sustainability for Mexico), CMES (Mexican council for sustainable buildings), ANES (National Association for Solar Energy), RENAC México (Renewables Academy), etc.

Neighbourhood Programme established in Mexicali, Baja California. It consisted of building 220 affordable houses with PV modules for self-generation and sale of excess electricity to the grid. Each household system is provided with bidirectional meters to measure separately the electricity sold to and bought from CFE. Both flows of electricity are billed at the retail rate [53]. Gischler and Janson [53] recommend to set an overall cap on eligibility, which must be consistent with targets imposed to RE based on their net economic benefits. This will allow to calculate the amount of intermittent energy provided to the network and the cost of it.

- Mexico must continue to complete a RE framework, including a methodology on the design of systems and their economic benefits, model contracts and metering arrangements for small-scale PV projects and establishing production targets that ensure economic benefits and installations´ feasibility. PV energy shall be beneficial for both customers and CFE.
- Mexico must establish total electricity production limits for small-scale PV projects. Those caps should be related to the grid capacity and technology, so it is possible to distribute and use the energy generated by small installations.
- CFE and CRE must improve all bureaucratic processes needed for planning and permitting PV installations. Currently, there is a lengthy and unclear process to obtain all required environmental, construction and connection permits. This makes it difficult or impossible to implement even viable projects, as they are blocked at the bureaucratic level and because they become more costly.
- Continue with the objectives and implementation of the ProSolar Programme (Programme for the promotion of PV systems in Mexico) [55]. This programme is being developed by SENER and a specialised group including CFE, GIZ, CRE, etc. The document published in 2012 explains Mexico′s potential for harnessing solar energy, especially PV. It includes five action strategies to encourage the use of PV energy through objectives set to 2017. So far, there are no specific financial incentives proposed in this programme.

3. *Training*
   - Develop education programmes for training skilled designers, architects, engineers, installers, managers and consultants specialised in photovoltaic projects.
   - Support the establishment of companies that could offer a complete service for its PV and BIPV customers, with projects tailored to their specific energy needs, architectural design, budget, occupancy and geographical location.
   - It is necessary to overcome people´s inertia to be afraid of changes. A transformation of paradigm on how we produce and use energy could be a medium and long term process. This could be achieved through effective public education, awareness and technical education programmes for preparing specialised people to be able to create or improve PV technology, and to design, install and maintain PV systems. Here, the role of the PV industry, federal and local governments, universities and research centres, professional and environmental organisations, and green building rating systems (such as LEED, LBC, and PCES[20]) becomes essential to extend a solid and strong PV industry in a sunny country such as Mexico.

[20] *LEED* stands for leadership in energy and environmental design is a sustainable building rating system developed by the US Green Building Council, and currently its use in Mexico is expanding (http://www.usgbc.org/leed accessed: 10.10.13). *LBC* stands for living building challenge is also a green building certification programme, more information about the programme can be found at http://living-future.org/lbc/about [accessed: 10.10.13]. *PCES* stands for *Programa de Certificación de Edificaciones Sustentables* (sustainable building certification programme), this programme began in 2008 and applies only to buildings located in Mexico City. More information can be found at: http://www.sma.df.gob.mx/sma/links/download/archivos/programa_certificacion_edificaciones_sustentables.pdf [accessed: 10.10.13].

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